EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN — A&B DEPARTMENT

AB-Note-2007-025 OP

Testing of the Pole Face Winding crimpings

Measurements carried out on the 100 PS main units before start up of the PS machine in 2007

O.Hans

Abstract

The crimpings of the Pole Face Windings (PFW), used to connect the rectangular copper conductor of the main windings with its supply cable, could have defects due to the manufacture process. They could lead to an extensive high electrical resistance.
To locate these defects, the PFW are powered with 80 Ampere DC and the voltage drop over the electrical resistances of the crimping is measured. The measurements are done between the PFW current leads and the corresponding pick-up. By subtracting the resistance of the supply cable and the interconnection cable the crimping resistance is calculated.

During the long shutdown 2005 and the annual shutdown 2006/2007 a total of 34 main units, and their PFWs, have been refurbished [1]. The refurbished main units are equipped with new PFW. On this PFW the crimping technique was improved and the defect of high crimping contact resistance should not appear. Nevertheless to have complete picture of the situation the 34 refurbished main units and the 66 none refurbished units were measured.

Geneva, Switzerland
May, 2007

1. Category of the PFW

Referring to the crimping resistance measurements, the PFW are rated in three categories. The highest crimping value of the four PFW determines the category of the main unit [2].

Category 1: Resistance < 150μΩ

Category 2: 150μΩ ≤ Resistance ≤ 400 μΩ

2A: Stable in time and close to category 1
2B: Resistance increases continuously. Close or risk in future being close to category 3.

Category 3: Resistance > 400μΩ

3A: 400μΩ ≤ Resistance ≤ 900 μΩ
3B: Resistance ≥ 900 μΩ

Nota: In the measurement the supply cable and the interconnection cable are included. For the classification these cables needs to be subtracted.
Supply cable: 240 μΩ
Interconnection cable: 440 μΩ

Following are the categories in terms of voltage drop (mV) acquired during the resistance measurement campaign (crimping, supply cable and the interconnection cable).

Category 1: **PFW Bottom:** U < 31.2
PFW Top: U < 66.4

Category 2A: **PFW Bottom:** 31.2 ≤ U ≤ 33.2
PFW Top: 66.4 ≤ U ≤ 68.4

Category 2B: **PFW Bottom:** 33.2 ≤ U ≤ 51.2
PFW Top: 68.4 ≤ U ≤ 86.4

Category 3A: **PFW Bottom:** 51.2 ≤ U ≤ 91.2
PFW Top: 86.4 ≤ U ≤ 126.4

Category 3B: **PFW Bottom:** U ≥ 91.2
PFW Top: U ≥ 126.4

2. Analysis of the PFW after the measurement campaign in March 2007

During the shutdown 2006/2007 all 100 main units with their total number of 400 PFW were measured. Of particular interest were:

- The PFW which were after the last measurements classified as category 3A.
- The PFW which were after the last measurements classified as category 2B.
- The 34 refurbished main units. The measurements should confirm the improved crimping technique applied in the manufacture process.

2.1. Naming conventions

Each of the 100 main units is composed of a focusing half-sector and a defocusing half-sector rigidly joint together [3]. The sector in which the beam enters the main unit is called upstream sector (French amont), whereas the sector in which the beam exits the main unit is called downstream sector (French aval). Each of the sectors has a top (French haut) and bottom (French bas) PFW.
The PFW includes two main windings, narrow and wide winding. The electrical connections for the narrow winding are called N4 and N10 and for the wide winding W8 and W9.

2.2. The current situation

Figure 2.1 shows the statistic of the different categories after the measurement campaign in March 2007. The main part, in total 73 main units, is in category 1 (not represented in the graph), followed by 20 main units in category 2B, four in 3A and three in 2A.

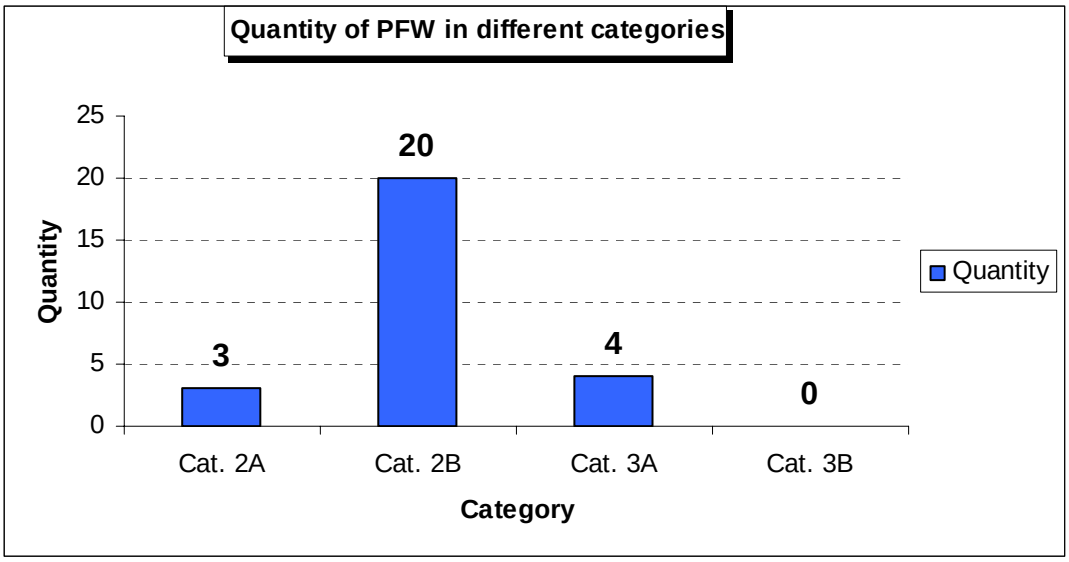

Fig. 2.1: Statistic of category after the measurements in March 2007

2.3. PFW within category 3A

The measurement campaign of the shutdown period 2005/2006 [4] showed a total number of 9 PFW within category 3A. Worst was main unit 31 with all four PFW in this category. Other main units having PFW in category 3A were main unit 01, 19, 48, 49, and 51. Main units 01, 19 and 31 were refurbished during the shutdown period 2006/2007 and equipped with new PFWs. New in this category is main unit 50 which had on the top downstream PFW a huge step from 41.2mV to 52.2 mV. This PFW moved from category 2B to 3A. Main unit 51 is coming close to category 3B. The crimping resistance of the other three PFW are increasing continuously.
Figure 2.2 shows an evolution graph of the category 3A.

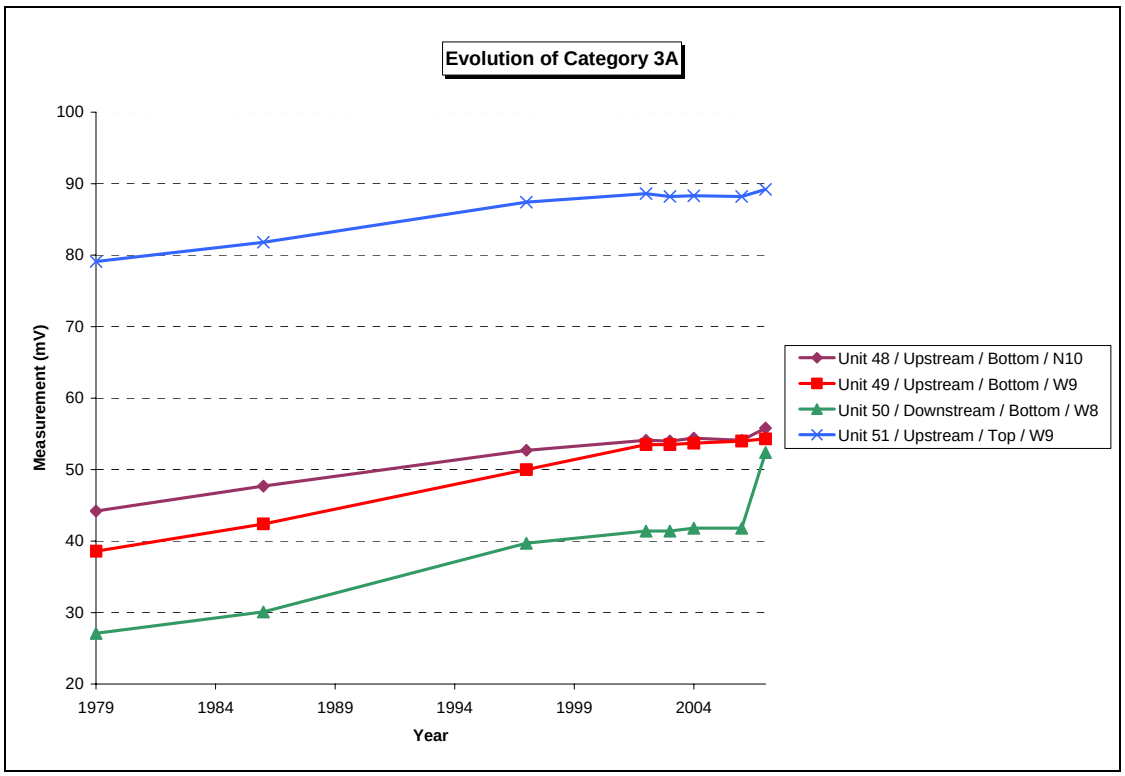

Fig. 2.2: Evolution of PFW within category 3A.

2.4. PFW within category 2B

The quantity of PFW within category 2B increased form 16 to 20. Main unit 26 shows a rapidly increasing resistance on the upstream top PFW. This main unit, as well main units 46, 75 and 76 are close to category 3A. All other PFWs show a tendency of a slowly but continuously increasing crimping resistance.
Figure 2.3 and 2.4 show the evolution in this category.

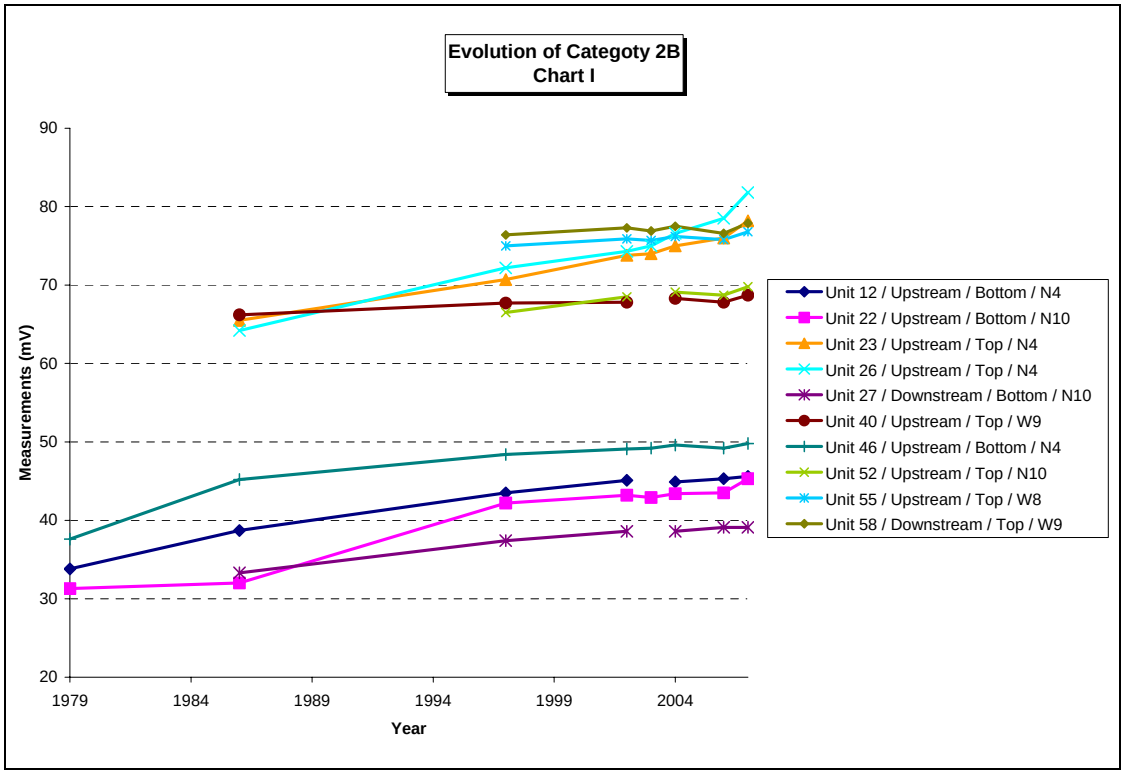

Fig. 2.3: Evolution of PFW within category 2B, chart I.

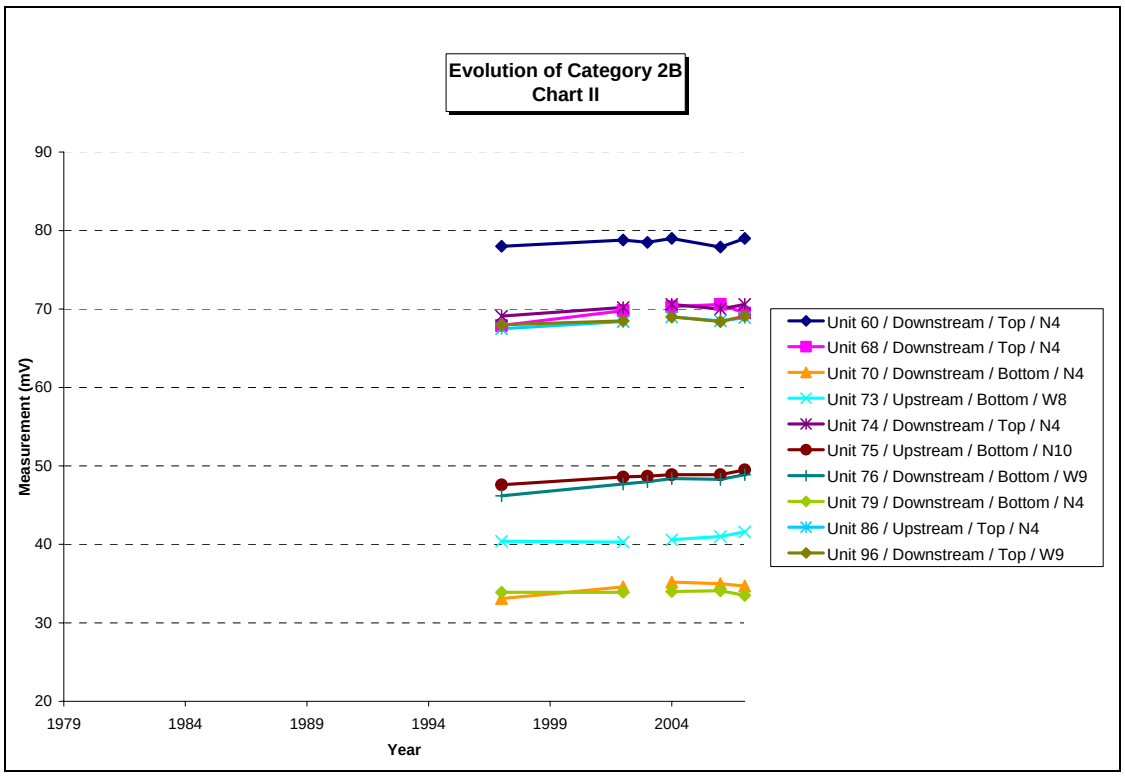

Fig. 2.4: Evolution of PFW within category 2B, chart II.

2.5. The 34 refurbished main units

During the shutdown period of 2005/2006, 26 main units were refurbished and their crimping resistance measured. These main units were one year later (during the shutdown period 2006/2007) re-measured. The comparison of both measurement campaigns showed that the new improved crimping technique gives a stable and low resistance contact.

Figure 2.5 shows the absolute deviation in mV of both measurement campaigns. All values are within in the resolution and precision of the measure equipment. The two peaks of unit 44 and 100 could be explained by the effect of a poor contact during the measurement (the measurement value for main unit 44 during the measurement campaign 2007 was 33mV lower than as for 2006). For the next shutdown these two main units will be re-measured.

The PFW of the eight refurbished main units of the shutdown period 2006/2007, have all a very low crimping resistance.

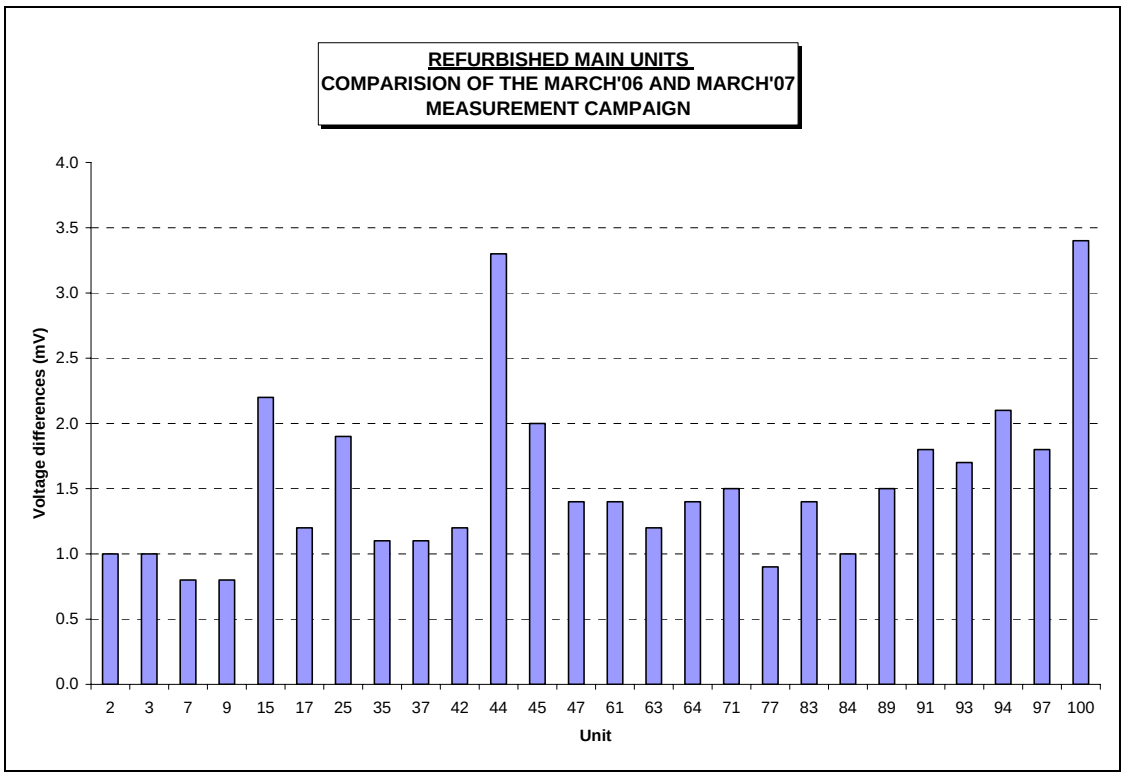

Fig.2.5: Comparison of the 2006 26 refurbished main units

3. Conclusion

During the last two shutdown periods, the magnet group did an important effort to refurbish as many main units as possible. This may be seen in the fact that the PFW crimpings are mostly in the lowest categories. The current situation looks stable and calm, except main unit 26 and 50.
I would like to thank the team of AT-MEL and AB-PO for their participation and assistance.

4. References

1. Th. Zickler et al., "Consolidation of the 45-year old PS main magnet system", CERN/AT 2006-6, CERN 2006
2. C.Germain et al., "Etat de l'aimant dy Synchroton PSR et ses perspectives d'évolution", PS/SM 83-5, CERN 1983.
3. K.H.Reich, "The CERN proton synchrotron magnet", MPS/Int DL 63-13, CERN 1963.
4. J.Ottaviani, "Aimant PS Controle de l'etat des sertisages internes des PFW….", AB-Note-2006-014 OP, CERN 2006.

5. Annex

Voltage readings measured during the measurement campaign 2007 and the crimping classification.

Annex 1

A.Newborough, P.Vidales, L.Moreno, O.Hans
Measurements done 09.November 2006 and 12 March 2007
Current 80A

	UPSTREAM																DOWNSTREAM															
	TOP								Bottom								Top								Bottom							
Magnet	N4	Cat	N10	Cat	W8	Cat	W9	Cat	W9	Cat	W8	Cat	N10	Cat	N4	Cat	N4	Cat	N10	Cat	W8	Cat	W9	Cat	W9	Cat	W8	Cat	N10	Cat	N4	Cat
1	64.5		53.3		52.8		52.9		18		16.2		18.1		18.9		51.9		52.3		52.9		52.7		15.9		18.3		15.6		19.4	
2	53.4		53		52.3		53.8		18.7		17.5		17.5		17.6		56.3		53.7		53.3		51.9		17.3		18		18		20.2	
3	56.1		51.4		53.2		50.7		17.1		18.3		17.3		19.6		52.1		53.2		54.2		54		17.2		17.4		17		18	
4	62		66.6	2A	57.8		62.2		17.4		16.9		18.3		18.8		55		60.2		57.8		58.2		27.4		27.8		24.1		23.7	
5	59.4		55.1		59.1		55		19.2		19.6		25.5		31.4		60.9		56.3		54.5		61.3		21.4		21.1		21.6		21.9	
6	57.2		56.6		55.4		55		24.4		28.2		21.8		28.3		59.9		55.5		54.5		54.8		19.3		20.9		18.1		19.2	
7	52.2		52.7		52.4		53.4		17.8		17.1		19.2		17.6		56.4		52.6		56.2		52		17.4		17.9		18		20.6	
8	55.3		51.6		54.6		52.5		17.8		17.6		17.6		19.7		51.6		52.9		51.8		53.1		17		16.8		16.7		17.1	
9	56.2		52.5		54.5		51.3		17.1		18.2		17.8		20.3		52.4		55.5		51.6		54.8		17.8		17.1		18.5		21	
10	59		56.8		56.8		53.7		19		18.6		19.6		22.9		53.8		60.6		54.7		56		19.9		20.8		19.8		19.2	
11	54.2		56.5		53.2		56.2		19.5		19.4		21.2		20.1		62		60.5		62.2		58.9		19.9		20.2		23.8		23.6	
12	60		59.5		58.6		63.9		24		19		18.4		45.6	2B	60.5		56.7		60.8		56.8		18.3		18		20.7		19.3	
13	55		55.8		57.9		56.8		21.3		23.6		28.6		23.6		56.9		53.2		56.2		64		23.6		19.2		22.2		20.7	
14	55		56.7		58.2		57.3		18		20		17.6		19.2		55.4		53.3		54.3		52.1		19		22.2		25.6		21.7	
15	55.5		53.8		53.5		51.9		17.1		19		17.5		21.6		53.3		52.9		51.2		53.7		17.3		18.3		16.9		17.9	
16	52.3		53.9		55.2		54.9		19.7		20.2		18		21		55.3		53.1		55.3		52.3		17.6		18.6		19.4		20.1	
17	55.2		56.5		53.2		53.2		17.1		19.5		17.7		21.1		51.5		64.4		51.2		53		17.4		17.3		16.4		23.3	
18	52.2		53.3		51.9		57.9		16.9		16.9		16.4		17.8		56.3		52		52.7		58.5		16.4		16.2		17		19.2	
19	50.9		52.2		52.5		52.5		16.6		16.6		16.3		24.4		56.9		52.2		52.3		50.4		16.7		16.9		17.3		19.5	
20	57.3		57.3		58.3		56.1		17.6		18.8		18.5		20.6		52.7		54		53.7		55.1		24.1		19		18.8		18.7	
21	58.5		53.8		54.6		53.6		18.2		19.3		20		20.4		57.8		59.6		54.5		56.4		20.9		19		18.6		22.2	
22	68.3	2A	60.1		59.3		59.3		27.6		26.5		45.3	2B	38.1	2B	53.8		54.7		54.1		57.2		18.2		21.5		18.6		18.1	
23	79	2B	78.2	2B	64.9		56.9		18.1		18.9		19.1		19.9		59.9		58.9		58.8		62.4		19.3		20.6		20.3		21.9	
24	55.2		55.9		52.4		56.1		23.2		18.8		21.1		18.7		56.4		54.3		53.8		53.1		22		20.6		22.8		24.5	
25	61.5		50.8		51.9		51.1		17.5		19.7		17.7		19.8		56.4		52.1		51.5		53.4		16.8		17.6		16.4		17.7	
26	81.8	2B	61.9		74.5	2B	63.7		26.3		22.9		39.2	2B	33.5	2B	55.7		74.9	2B	58		55.9		27.6		23		31.1		25.4	
27	54.5		54.6		65.8		55.9		24.2		28.1		22.8		25		62.3		58.1		58.1		57.3		20.4		29.5		39.1	2B	27.8	
28	56.6		57.7		56.2		56		26.7		26.1		23.8		23.3		69.6	2A	56.7		58.4		60		32.4		28.8		20.3		22	
29	58.2		54.7		55.5		54.2		20.7		21.4		21.6		23.2		53.8		53.9		53		54.7		18.5		19.2		19.3		23.8	
30	57.7		55.5		56.1		55.8		19.3		19.1		21.7		22.3		53.6		54.8		53.8		55.9		19.6		21.9		19.9		19.7	
31	55.2		50.1		51.6		49.9		16.9		16.8		17.3		22.5		49.6		50.9		50		51.4		17.8		18.2		16.5		17.9	
32	60.8		55.9		56.4		57.2		19.5		19.1		20.7		22.2		56.7		58		59.5		56.4		19.4		18.3		17.8		19.2	
33	54.7		54.4		56.6		55.7		19.6		18.6		18.3		22.4		59.3		54.9		58.6		56.3		21		20.8		20.7		22.5	
34	57.3		53.6		55.1		52.7		18		19.3		18.4		20.1		53.9		63.8		56.7		57.5		19		19.2		18.3		21.2	
35	55.4		52		53.5		51.2		17.2		17.5		17.8		19.4		52.7		52.2		51.7		53.4		17.2		17.2		17		17.3	
36	58		56.8		57.2		55.9		20.6		22		19.8		21		53.7		55.8		53.7		56.6		17.9		21.3		18.5		18.9	
37	56.6		53.1		53.6		52.5		17.6		18.9		17.8		20.8		52.9		54.1		52.3		54.5		17.9		17.3		17.9		18.5	
38	59.2		55.9		56.9		54.4		19.4		23.3		23.3		23.3		53.4		53.5		53.8		54.6		22.5		23.3		21.4		21	
39	59.2		54.6		57		54.7		17.9		18.5		19.3		23.3		54.2		55		54.1		55.5		18.9		20.1		17.9		19	
40	56.8		55.8		58.3		68.7	2B	20.3		20.9		18.2		21.5		58.8		56.4		55.5		53.3		19.6		19.2		23.5		21.9	
41	56.8		53.4		55.7		53.1		19		20.6		20.2		20.8		54.9		54		53.9		56		22.4		21.7		19.4		20.3	
42	56.5		52.2		54.1		51.3		17.5		20.3		23.1		27.2		52.7		52.6		51.7		53.3		17.7		17.1		17.2		18.7	
43	59.3		54		55.5		54.9		17.9		20.8		19.4		21.1		54		54.9		54		55.3		18.7		19.6		18.7		19.1	
44	57.7		52.1		56		52.1		17.9		18		20		20.6		57.8		53.8		53.7		54		19.1		17.5		19.2		17.6	
45	55.3		58.6		53.6		51		17		17.7		17.7		20.5		52		52.4		51.6		53.7		17.2		17.4		17		18.4	
46	64		67.2	2A	66.1		69.3		25.6		25.1		34.4	2B	49.8	2B	55.8		56.1		55.5		56.7		30.9	2A	42	2B	26.9		24.7	
47	54		52		52.4		53.4		17.7		23.2		17.2		18.1		56.1		51.8		52.9		51		17.8		17.9		18		20.6	
48	69.2	2A	76.7	2B	70.3	2B	60.4		24.1		46.5	2B	55.8	3A	22		56.2		56.9		58.5		58.9		24.4		23.1		28.5		25.9	
49	62.8		57		56.8		53.9		54.3	3A	27.5		47.2	2B	31		52.8		53.4		51.7		53.9		17.3		16.9		17.1		17.7	
50	77.2	2B	73.78	2B	62.3		62.4		18.2		19.2		19.4		20.8		67.7	2A	56.1		67.9	2A	63.8		36	2B	52.4	3A	29.8		30.9	

	UPSTREAM																DOWNSTREAM															
	TOP								Bottom								Top								Bottom								
Magnet	N4	Cat	N10	Cat	W8	Cat	W9	Cat	W9	Cat	W8	Cat	N10	Cat	N4	Cat	N4	Cat	N10	Cat	W8	Cat	W9	Cat	W9	Cat	W8	Cat	N10	Cat	N4	Cat
51	76.3	2B	69.7	2B	62		89.2	3A	19.3		22.4		21.6		27.6		59.3		60.4		56.9		64.3		32.3	2A	30		23.5		26.5	
52	60.5		69.8	2B	59.6		69.5	2B	16.9		16.9		18.3		19.8		55		58		53.5		60.3		21.6		18.4		20.9		19.1	
53	52.5		54.4		54.8		54.6		19.4		22		19.8		28.6		56.1		54		53.6		52.1		25.5		22.7		19.7		24.5	
54	61.4		53		58.8		55.9		20.2		20.3		19.7		20.9		57.3		54.7		52.9		61		21.1		20.8		24.6		23.6	
55	71.4	2B	57.9		76.8	2B	70.5	2B	20.5		20.8		20.6		24.5		70.3	2B	57.2		56.7		61.5		35	2B	21.5		28.3		34.3	2B
56	57.4		63.9		5.7		60.8		17.9		18.9		18		19.7		57.5		58.8		56.7		56.6		19.4		27.3		18.8		21.3	
57	57.6		55.6		54.7		55.1		18.4		20.5		24.6		22.6		55.7		56.1		55.2		58.6		19.6		23.7		24.3		30.5	
58	57.4		61.1		62.8		60.5		32	2A	26.2		25.5		34.9	2B	73.4	2B	65.6		60.4		77.9	2B	20.4		23.6		21.7		27.8	
59	58.8		54.8		57.6		52.9		23.1		20.4		21.8		32.9	2A	60.1		59.9		58.1		63.1		29.8		26		26.4		25.3	
60	59.3		56.3		61.1		61		21.1		22.6		25.5		24.1		79	2B	64.7		77.5	2B	58.6		18.1		18.8		19.3		20.4	
61	55.1		50.3		51.6		50.1		17		17.4		17.3		20.7		52.6		52		50.4		52.1		16.8		16.8		16.3		17.2	
62	51.2		53.1		50.6		53.1		16.9		17.2		16.8		17.1		56.3		51.9		53.2		51		16.6		16.5		18.7		18.9	
63	55.6		51.8		52.4		50.2		17.3		18.3		17.8		21		50.9		51.7		50		51.9		18.1		17.2		17.5		18.2	
64	49.4		49.6		48.1		50		16.8		18.4		16.4		21		54.4		50.3		52.4		49.2		16.5		16.6		16.9		18.9	
65	55.2		52.7		53.8		51.5		19.7		19		18.6		19.7		54.3		59.2		51		55		18.2		18.2		18.1		19.5	
66	55.4		52.8		53.2		51.9		21.7		18.8		21.6		20.8		54		53		53.4		55.5		18.3		18.3		16.9		22	
67	50.9		53.1		53		53.8		17.8		18		17.5		18.3		56.1		53.5		54.1		52.6		18.3		20		19.3		20.3	
68	51.7		54		53.4		55.3		17.4		17.7		17.6		20.1		69.5	2B	52.2		52.4		50.7		17.2		21.6		18.3		20.2	
69	55		56		52.4		57		16.9		17		19.2		19.7		55.8		53.9		51.2		53.8		23.4		22.1		20.9		19.3	
70	54.8		52.5		53.3		51.5		19.3		18.9		23.4		19.8		51.7		52.6		50.2		51.9		18.4		16.6		28.5		34.7	2B
71	54.3		52.3		51.1		51.2		17.2		17.9		17.6		20.2		52.8		52.2		52		52.9		17.4		16.9		16.7		17.7	
72	57.7		53.6		56.4		53.5		17.6		16.2		20.2		21.5		52.4		53.5		52.2		54.2		19.7		18.6		21.1		19.8	
73	52.5		57		52.3		53.3		27.5		41.6	2B	19.6		17.6		60.1		55.2		54.7		53.3		17.4		16.8		18		21.5	
74	60.3		58.5		62		61.4		27.2		25.4		21.4		22.2		70.6	2B	56		59.3		56.6		22.4		28		23.6		22.7	
75	71.7	2B	62.2		73.6	2B	62.8		27.9		31		49.5	2B	34.8	2B	57.8		59		56.9		58.3		23.1		23.9		39.5	2B	25.6	
76	66.1		61.3		60		72.1		22.2		44.5	2B	21.4		24.5		64		60.6		59.8		57.3		48.9	2B	26.3		29		30.5	
77	54.8		49.9		52.2		50.4		17.2		17.3		17.9		19.4		50.3		51.6		51		52.5		17.5		17.1		16.6		17.3	
78	57.9		53.2		53		51.8		17.7		16.2		19.9		20.3		55.1		54		54.9		55.6		21.4		19.6		18.4		18.2	
79	50.4		52		49.9		53.9		21.9		16		17		18		57.7		54.9		54.1		55.6		19.2		16.9		20.7		33.5	2B
80	66.3		53.8		51.9		52.8		24.8		16.7		18.7		23		52.8		52.9		50.4		52.9		20.5		16.8		18		20.1	
81	54.6		52.4		52.5		51.4		17.2		16.9		18		19.5		52.8		52.4		52.5		56.3		17		17.1		16.7		17.5	
82	55		51.9		52.4		51.3		16.6		17		17.1		18.9		49.3		49		48.5		50		17.9		17.2		16.2		16.9	
83	52.7		58.1		51.5		53.1		17.6		20.7		22.7		17.9		54.6		52		53.3		50.7		17.2		17.3		17.7		19.1	
84	54.9		51.9		52.9		51.3		16.9		16.8		17		18.8		53.8		52.3		52.3		53.3		17.1		17.4		17		17.4	
85	53.9		51.5		51.5		50.6		17.2		17.2		22.8		19.5		50.7		51.4		49.4		51.4		19.3		18		18.3		18.6	
86	68.9	2B	56.6		58.7		55.4		28.1		24		23.3		25.9		54.9		57.2		61.3		55.5		21.1		23.3		20.1		23.7	
87	53.2		55.1		58.3		57.5		23.7		17.6		18.4		18.5		65.9		72.9	2B	61.1		65.1		21.8		18.6		19.5		20.3	
88	51.6		53		51.7		54.7		18.9		16.7		17.7		17.7		57.4		52.4		52		52.9		17.6		19		18.6		19.8	
89	54.2		52.2		52.6		50.8		16.8		17.9		17.6		19.6		50.4		51		49.9		52.41		16.8		17		16.7		17.4	
90	58		52.3		57		55		24.5		18.7		18.7		20.2		53.9		52.4		51.5		54.1		21.4		17.5		18.8		16.9	
91	53		49.8		51.6		49.2		18.8		16.3		17		20.4		51		51		50.2		51.6		16.3		16.7		16		21.9	
92	57.8		54.5		55.2		54.5		18.6		19.4		19		20.5		54.1		55.3		59.3		62.1		40.6	2B	14.8		19.9		19.1	
93	50.2		51.3		49.8		52.1		16.7		16.5		15.9		16.8		54.2		50		52		50.7		16.3		17		17.6		18.7	
94	57		49.9		51.4		49.8		16.2		17.9		16.4		18.4		51		51.3		49.3		51.3		16.3		16.6		15.5		17.3	
95	54.1		50.9		52.8		52.4		17.7		19.5		20.4		22.1		55.9		56.2		50.6		55.4		19.2		18.6		20.2		19.1	
96	57.6		57.1		56		54.2		20.3		20.1		20.7		20.9		61.3		59.5		58.7		69.1	2B	20.9		20.4		20.3		23.8	
97	53.1		50.6		52.2		51.7		17.2		17.7		18		20.9		50.1		51.1		50.4		51.4		17.1		16.7		16.4		17.3	
98	57.9		53.2		54.1		54.2		18.2		20		19.2		23.1		52.2		53.2		62.5		56		21		19.6		19.5		18.8	
99	52.3		56.2		58.9		56.4		18.2		19.5		18.2		18.8		60		54.6		55.2		53.4		21.7		28.8		22.8		22.9	
100	54.1		50.9		52.2		50.5		19.6		17.8		19.8		21		52.1		50.5		50.9		51.8		18.7		18		16.4		21.2	